# THE MINOS TIMING SYSTEM:
# A NOTE CONCERNING THE FUNDAMENTAL OPTIONS

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# 1. Introduction

In the document describing the proposed MINOS timing system, two alternative modes of operation are discussed, along with a number of related options. These do not have any major impact on the hardware design, or project planning, but concern the way the system operates in quite fundamental ways. To try to clarify the issues, they are summarized in this note.

# 2. Alternative Operating Modes

## 2.1 GPS generates the timing signals

The GPS timing receiver provides 10MHz clock and 1 per second pulse outputs, both locked to GPS time. These are directly used by the timing distribution system, which serves largely to distribute them, although in slightly modified form.

## 2.2 Locally generated timing signals are timestamped by GPS

The timing distribution system has its own 10MHz master oscillator, which it divides down to produce a 1 per second pulse, and combines to produce the signal which it distributes. This provides a stable local time, but one which drifts slowly against GPS time. The two are related by using the GPS receiver to record the time of the locally generated seconds signal.

The front end electronics then record timestamps directly in terms of the local time, and the offset between local time and GPS is also recorded. I would envisage that all data is recorded and processed in terms of 'local time'; correction to GPS would only be done at the end, to relate events to the spill timing.

The offset between GPS and local time has to be stored in the database. But since this only changes slowly with time, the volume of data is low: one value every 20 minutes is ample.

# 3. Consequences

## 3.1 Near detector requirements

The near detector electronics are clocked with the 53MHz accelerator clock. It is thus not possible simply to generate all the timing signals from GPS, so the first mode does not apply, at least without modification. The second is always applicable; whatever periodic marker is produced by the timing system (whether a signal for each spill, or an approximate second signal from dividing the accelerator clock) can be timestamped by GPS.

The first mode might be used, but with modification. For example, the seconds pulse from the GPS could be used in conjunction with the accelerator clock, if it is resynchronized to the clock before distribution. This is needed to ensure unambigous synchronization across the detector. It adds an inconsequential amount of jitter, and causes number of clock cycles in each second to vary by one.

I am assuming the second mode, since it is sure to be applicable, but do not rule out the first. It is possible that GPS is not required at all; a signal provided from the accelerator control system may already be related to GPS time. This may not be probable, but needs checking.

## 3.2 Effect of problems with GPS reception

Of some concern is what happens if the GPS signal is lost for an extended period. This is an issue particularly at Soudan, where extreme cold, snow, and icing may be a problem.

This will be addressed in the design of the antenna installation, but without an unreasonable amount of effort (field testing in Alaska?) it will be impossible to be sure that the solution is adequate.

When the signal is lost, the receiver clock will drift slowly from GPS time. With a good receiver, it should be no more than 10μs in the first day, but with an increasing rate of drift. (To achieve this may need the receiver to be at a reasonably constant temperature). This should be more than adequate, provided we are not relying locating events relative to the coarse structure of an 8μs spill.

If the timing is generated locally from a rubidium clock, the drift rate will be considerably less than with a GPS receiver that does not have one. Further corrections, when the signal is restored, can also be made retrospectively. All this can be equalled with a GPS system, but not with the normal timing receivers.

### *3.3 Effect of loss of connection down mine*

Possibly of more concern at the mine is the possibility of damage to the fibre optic cable down the mine. If the timing is generated from a GPS receiver on the surface, this could completely stop the detector operation. Such an event may be improbable, but the time to replace the cable could be quite long: days, at least.

In comparison, with local generation of timing, the system continues to operate. Timing will drift, but slowly: with a rubidium oscillator, under 100μs in a month. And by using the neutrino events, accuracy to ~1μs can be maintained indefinitely. (Yes, GPS isn't really needed in normal operation!).

### *3.4 Consistency of approach*

It is unnecessary, but would be nice, to have a similar timing system at both detectors. It keeps the hardware as similar as possible, and the software also. It seems easiest to arrange this by using locally generated timing, timestamped by the GPS receiver.

It would admittedly be simpler if the timing on both detectors could be directly derived from GPS.

### *3.5 Achieving highest accuracy timing*

For normal accuracy requirements, there is no difference between the two methods. However, if accuracy sufficient to associate events with the particular rf bucket, or better, is required, normal GPS timing is not adequate. The easiest way uses the neutrino events themselves for synchronism. This needs an extremely stable clock.

For this, local generation of timing is best. The rubidium clock proposed for the central unit is sufficient, at least at the rf bucket level. If even that proves insufficient, it is trivial (though not cheap!) to upgrade later to use a better external clock. GPS receivers are available with internal atomic clocks, but this is likely to be a harder and more expensive upgrade.

This comment only addresses the far detector. High stability would have to be achieved at the near detector also; this can be done, but possibly not so cleanly.

There is no stated need for higher timing accuracy, but reasons for wanting it are imaginable (if improbable).

### *3.6 Network timing*

Hardware timestamping in the front end electronics gives only the high resolution part; the rest is added in software using the processors' local clocks, synchronized by time information passed over the network from one computer acting as a network time server. This in turn is tied to GPS time. The way this is done is slightly different in the two modes, though similar in general principle.

With GPS generating the timing signals, the time server uses GPS time messages over the control interface to the receiver to steer its local clock into synchronism with GPS.

With locally generated timing signals, it is a bit different. The time server is passed the generated seconds pulse, and synchronizes its local clock to this. The GPS time of each second pulse is read from the receiver, and is used to determine the offset between 'local' and GPS time. The first time read after a system reset can be used to set the local time, so that it is approximately the same as GPS; with a good local master clock, the difference will never grow to more than one second.

The difference between the two is of little practical consequence.

# 4. Related Options

## 4.1 GPS receiver location

It would obviously be preferable to put the GPS receiver underground, at the detector. It is simpler for installation and maintenance, and makes additional facilities of the receiver usable without adding fibre optic links. The problem it that it needs a very long antenna feed.

At the near detector it looks reasonably simple, using low loss coax and a booster amplifier, and this approach is assumed. If there are problems, there are relatively few disadvantages in moving the detector to the surface.

At the mine it is more difficult, as the feed it too long for a simple electrical system, even with amplifiers, to look practical. So the baseline option was to put the receiver on the surface, with all its interface signals taken over fibre optic links down to the detector.

However, a fibre optic antenna link able to work to 2km is commercially available. This would allow the receiver to be installed underground, using only commercial equipment. This is an attractively elegant solution, and I would consider it preferable. The reliability of this system has been questioned (though the general approach is widely accepted in the mobile phone industry), but it will be investigated.

## 4.2 Fallback from GPS generated timing signals

If the receiver is on the surface, and is being used to generate the timing signals, any fault on the fibre-optic links will completely stop detector operation. For equipment faults this is (relatively) acceptable, as the faulty unit can be quickly replaced. For a cable fault, such a rapid repair will not be possible, if the damage affects all the fibres including the spares. While this seems improbable, it is not inconceivable.

A partial solution is to provide a fall-back operating mode which does not depend on the GPS signals. This means providing a local oscillator and division to give a seconds pulse, and providing a way of switching over to it. The ideal would be a high quality oscillator, and smooth, automatic, and glitch free transition. This makes this 'simpler' operating mode actually the more complex. A compromise solution might be adequate: for example, a good quality crystal oscillator, and manual switch-over (using a locking switch).

Note that the alternative is to try to make the fibre link acceptably robust. A separate spare cable, rather than relying on spare cores in one cable, would be a major but possibly expensive improvement. Using an armoured cable would also be a great help, but as well as being expensive might be excessively difficult to install.

### *4.3 Local master clock quality*

If the timing is generated from a local master clock, it seems worth fitting the best quality that can reasonably be afforded. This is a low cost (~$1500) rubidium type, which gives much better performance than even the best ovened crystal oscillator.

If the timing is generated from GPS, and a local oscillator is fitted only as a fall-back, then either an ovened crystal oscillator, or a top grade temperature compensated one, may be all that is justified. However, there is then an argument for providing a trim adjustment and means of comparing its output frequency to GPS, so it can readily be set close to its nominal frequency. This is an undesirable complication.

The central unit will be made to accept a variety of types of master clock. Even if a rubidium clock is fitted to the operational unit, it may be a worthwhile cost saving to fit a lower quality oscillator to some of the spares and lab units.

Note that at least a low cost crystal oscillator will be fitted internally, to permit functional test of the unit with no external input.

## *5. Personal Opinion*

1) I would prefer to put the far detector receiver down the mine, with a fibre optic antenna link, and generate the timing signals directly from it. The near detector, also with the receiver underground, would operate in whichever mode its timing system required.

   This is the simplest hardware system, with least custom electronics, and reduces the effects of damage to the mineshaft optical cable to an acceptable extent.

   It does however depend on the fibre optic antenna link proving acceptable. This needs investigation.

2) My second choice would be to generate the far detector timing from a local rubidium clock, and use the GPS receiver on the surface to timestamp the seconds signal. The near detector would probably also use the GPS receiver to timestamp its signals.

   It is a reasonably simple system, and gives the best performance and best tolerance of faults without adding complexity. And it allows easy upgrading for the best possible timing performance.

3) My third suggestion, least preferred, is to generate far detector timing from a GPS receiver on the surface, and take whatever precautions are necessary to ensure the fibre optic cable is adequately reliable: either or both a spare cable and armouring.